

SPATIAL REORIENTATION OF SENSORIMOTOR BALANCE CONTROL IN ALTERED GRAVITY

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INTRODUCTION

Sensorimotor coordination of body segments following space flight are more pronounced after landing when the head is actively tilted with respect to the trunk. This suggests that central vestibular processing shifts from a gravitational frame of reference to a head frame of reference in microgravity. A major effect of such changes is a significant postural instability documented by standard head-erect Sensory Organization Tests. Decrements in functional performance may still be underestimated when head and gravity reference frames remained aligned. The purpose of this study was to examine adaptive changes in spatial processing for balance control following space flight by incorporating static and dynamic tilts that dissociate head and gravity reference frames. A second aim of this study was to examine the feasibility of altering the re-adaptation process following space flight by providing discordant visual-vestibular-somatosensory stimuli using short-radius pitch centrifugation.

METHODS

Pre- and post-flight measurements were obtained on 11 astronauts (7 males, 4 females). Each participant was a first-time flier on Shuttle flights 11 - 13 days in duration. Each subject participated in one familiarization training session, three pre-flight data sessions (L-60, L-30 and L-10 days), and four post-flight data sessions on R+0, 2, 3, and 7-8 days. Each test session included posture measurements, and three sessions (L-60, L-30 and R+3) repeated the posture measurements immediately after exposure to short-radius centrifugation. Balance control was evaluated using a computerized dynamic posturography system (NeuroCom Equitest). Infrared markers were used to quantify head and body kinematics using an OptoTrak (NDI, Ontario). Each experimental session consisted of twelve 20 s trials conducted with eyes closed using a combination of support surface and head tilt conditions. The support surface was either fixed (SOT-2) or sway-referenced in the sagittal plane in direct proportion to the estimated instantaneous center-of-mass sway angle (SOT-5). Subjects were instructed to either maintain their head position erect, tilted by 20° (extended back or flexed forward), or perform continuous $\pm 20^\circ$ dynamic pitch tilt oscillations at 0.33 Hz paced by an audible tone transmitted through lightweight headphones. Postural stability was assessed using both deviations from upright (peak-to-peak and RMS sway) and convergence toward stability limits (time and distance to base of support boundaries). The centrifugation stimuli were patterned from a previous Spacelab experiment, and consisted of pitch rotation about an Earth-vertical axis (left side down) with the interaural axis positioned 0.5m off-axis. Subjects rotated at a constant rate of 140°/s in either forward-facing or backward-facing directions for 60s, followed by superimposed sinusoidal oscillation for one min each in darkness, with a matched vertical optokinetic stimulation at the same frequency, and then again in darkness. The optokinetic pattern (stripes on a cylindrical display at 0.5 m) moved 180° out of phase with the centrifuge oscillation in the forward-facing direction and in phase with the centrifuge oscillation in the backward-facing direction.

RESULTS

Consistent with our previous post-flight studies, postural stability on R+0 was substantially decreased for conditions with absent visual and altered proprioceptive feedback. The most striking result; however, was on trials requiring dynamic head movements at 0.33 Hz. On landing day, all eleven subjects fell on at least one SOT-5 trial with active head movements (falls on 18 of 23 trials overall). The recovery curves for these crewmembers for trials with head erect followed similar trajectories as those demonstrated by previous astronaut data recorded by our laboratory. The recovery profile for trials with the head tilts and head movements, in contrast, had a similar recovery time constant but at lower performance levels compared with the head erect trials. Postural performance during the post-flight recovery phase had been previously compromised in some subjects by repeated exposures to short-radius off-axis pitch rotation (Black et al, J Vestib Res 9:369-78, 1999). Limited exposure to similar pitch centrifugation profiles on R+3; however, did not substantially disrupt postural performance in any of the subjects tested in this study.

DISCUSSION

The decrease in performance during head tilts is consistent with our hypothesis that changes in the central vestibular processing of otolith input contributes to the disruption of balance control following g-transitions. Based on the results of this study, head tilts during posturography have been implemented as a medical requirement for functional neurological assessment following both short- and long-duration missions.